

PRODUCT TO TAILOR DISTRIBUTIONS OF ENERGY DEPOSITION BY A HIGH ENERGY PHOTON BEAM

[0001] This application claims priority benefit of U. S. provisional application no. 60/506,792 filed September 29, 2003, which is incorporated herein by reference.

[0002] The product uses magnetic fields and density differences to tailor distributions of energy deposition caused by a high energy photon beam. For example, the product can combine a magnetic field with a difference in density between a target volume in a body and the body proximal the target volume to increase energy deposition in a target volume in a body relative to parts of the body other than the target volume.

[0003] Though the product can be useful in radiation therapy for cancer, the product can also be used in various other applications, such as in materials technologies, where it can be useful to tailor distributions of energy deposition by a high energy photon beam.

[0004] The product results from unexpected discoveries made in research with the product claimed in U. S. patent US05974112 (also referred to as 5,974,112), issued 26 OCT 1999, which is incorporated herein by reference.

[0005] The product taught in U.S. patent no. US05974112 comprises a magnetic field having a high gradient along a high energy photon beam path. As the photon beam enters a body, high energy electrons are produced by the photons via scattering and pair production. Thus, an electron-photon cascade proceeds along the beam path with the electrons losing energy to the body.

[0006] When the electrons enter the high field region along the magnetic field gradient, the Lorentz force on the electrons causes these electrons to lose more energy in this region than would be the case without the magnetic field. Thus, when the high field region is at a target volume in the body, more energy is deposited in the target volume than would otherwise be the case and, since electrons have been thereby removed from the beam, less energy is deposited in a region beyond the target volume than would otherwise be the case.

[0007] Unexpectedly, in research with this, other ways have been found to tailor a relationship with a body, a target volume in the body, a magnetic field, and an electron-photon cascade in the body produced by a photon beam, where the photon beam and the electron-photon cascade proceed substantially parallel to a beam path.

[0008] FIG. 1 shows a magnetic field source 11 proximal a body with a target volume in the body irradiated by a photon beam 41.

[0009] FIG. 2 shows a magnetic field source 11A inserted in a cavity in a body proximal a target volume in the body irradiated by a photon beam.

[0010] FIG. 3 shows a inserted volume in the body between the photon beam and the target volume. A source of the magnetic field is not shown here as the source could be an external source as in FIG. 1 and could be an internal source as in FIG. 2 and could be combinations of these.

[0011] The product to tailor energy deposition comprises a magnetic field which is in a preset tailoring relationship with a body 31, 31A, 31B; a target volume 21, 21A, 21B in the body; and a electron-photon cascade in the body produced by a photon beam 41, 41A, 41B; where the photon beam and the electron-photon cascade proceed substantially parallel to a beam path which is centered on a beam axis 101, 101A, 101B, and can be non-parallel to a field axis 102, 102A, 102B. In one form, the photon beam and the electron-photon cascade proceed substantially parallel to a beam path which is centered on a beam axis 101, 101A, 101B, and is orthogonal to a field axis 102, 102A, 102B.

[0012] It is believed that in most, if not all, forms of the product the magnetic field has a component in the target volume parallel to the field axis of at least one hundred gauss.

[0013] The target volume has a target density. The body has a body density proximal the target volume.

[0014] The magnetic field can have a gradient along the beam axis, and need not have this gradient.

[0015] The magnetic field can be produced by any magnetic field source and by any combinations of magnetic field sources.

[0016] The tailoring relationship causes a desired distribution of energy deposited in the body and the target volume.

[0017] In a form of the product, where the target density is least thirty percent greater than the body density, the preset tailoring relationship can also comprise a component of the magnetic field in the body proximal the target volume parallel to the field axis, of at least one hundred gauss.

[0018] This magnetic field tailors the energy deposition to be higher in the target volume than it would be without the magnetic field. Unlike the case in the issued patent US05974112, referenced above, this magnetic field need not have a high gradient along the beam path.

[0019] In this form of the product the magnetic field can be produced by a magnetic field source inserted 11A in a cavity 32A in the body.

[0020] In all forms of the invention the magnetic field source can be an external source as indicated in FIG. 1, can be several external sources, can be an internal source as indicated in FIG. 2, can be several internal sources, and can be various combinations of these.

[0021] In this form of the product the inserted magnetic field source can be chosen from a plurality of graded magnetic field sources in order to match the cavity and desired the tailoring relationship.

[0022] In a form of the product the tailoring relationship can comprise an inserted volume **14B** inserted in a cavity **33B** in the body between the photon beam and the target volume and also comprise a component of the magnetic field parallel to the field axis axis in the inserted volume, of at least one hundred gauss, where the inserted volume differs in density by at least twenty percent from the body density.

[0023] The inserted volume can have a density at least twenty percent less than the target volume density. In this case the combination of the magnetic field and the inserted volume will tailor the energy deposition to have a lower value just after the inserted volume, than would be the case without the inserted volume.

[0024] The inserted volume can have a density at least twenty percent more than the target volume density. In this case the combination of the magnetic field and the inserted volume will tailor the energy deposition to have a higher value just beyond the inserted volume, than would be the case without the inserted volume.

[0025] In a form of the product when there is a magnetic field gradient along the field axis, then the tailoring relationship can comprise sizing a first exposure of the photon beam so that it irradiates a first slice **22** of the target volume parallel to the photon beam, and sizing a second exposure of the photon beam so that it irradiates a second slice **23** of the target volume parallel to the photon beam, where the magnetic field is changed to be substantially the same in the second slice during the second exposure as in the first slice during the first exposure.

[0026] In this form of the product the magnetic field can be changed for the second exposure by moving a magnetic field source **11** along axis **102**.

[0027] Alternatively, in this form of the product, the tailoring relationship can comprise a photon beam energy gradient parallel to the field axis **102**, which matches the magnetic field gradient so that substantially the same energy is deposited in a first slice **22** of the target volume parallel to the photon beam as in a second slice **23** of the target volume parallel to the photon beam.

[0028] In all forms of the product a magnetic field source can be chosen from a plurality of magnetic field sources.

[0029] One magnetic field source from the plurality of magnetic field sources can be the external magnetic field source depicted in FIG. 1. Another magnetic field source from the

plurality of magnetic field sources can be the external magnetic field source depicted in FIG. 2.

[0030] A first magnetic field source from the plurality of magnetic field sources can have a first magnetic field configuration. A second magnetic field source from the plurality of magnetic field sources can have a second magnetic field configuration which is different from the first magnetic field configuration. An *i*th magnetic field source from the plurality of magnetic field sources can have an *i*th magnetic field configuration which is different from the first magnetic field configuration and different from the first magnetic field configuration.

[0031] At least one magnetic field source from the plurality of magnetic field sources can be a superconducting magnet.

[0032] At least one magnetic field source from the plurality of magnetic field sources can have any power and cooling needs attached via a flexible conduit.

[0033] At least one magnetic field source from the plurality of magnetic field sources can comprise a configuration of several electromagnets.

[0034] At least one magnetic field source from the plurality of magnetic field sources can have a face which is warmed only temporarily for use.